Experiences with CO2 Supermarkets in New Zealand

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ABSTRACT

CO_2 secondary systems were determined to be a good choice for supermarket refrigeration in New Zealand and Australia with emphasis on energy efficiency and reduced carbon footprint. Through March 2008, three sites have been successfully installed in New Zealand and one in Australia, and additional sites are planned. Compared to similar R404A direct expansion systems, overall warming effect was reduced 29%, R404A charge was reduced 74%, and energy use was reduced approximately 5% on average. Due to very high volumetric capacity of CO_2, care should be taken not to turn on all cooling loads at once. Timers were used to ensure loads would be staged on after, for example, an unplanned shutdown. To ensure adequate temperature control, individual display cabinet control is recommended.

1. INTRODUCTION AND TIME LINE

Beginning in 2002, an engineering consulting firm in New Zealand began research, and determined CO_2 as the best likely alternate to HFC's. In 2004 and 2005, customers were contacted to critique alternate CO_2 system options with the consultant. Brine secondary systems were discounted due to high pumping power requirements and secondary heat exchanger losses, particularly on low temperature systems. Key criteria for evaluating systems were energy efficiency and reduced carbon footprint. In June 2005, the consultant and customer completed a joint study and tour of sites in Europe to confirm best CO_2 systems and practices. In July 2005, sub-critical cascade CO_2 with direct expansion low temperature and liquid overfeed medium temperature was selected as the best solution. The customer requested Hussmann involvement to support development. In September 2005, testing and development at Hussmann, Bridgeton, MO, USA began using a single display case with pumped liquid CO_2. In February 2006, two sites were identified by the customer with opening dates November 2006 and March 2007. Figure 1 shows locations in New Zealand.

Figure 1: First Three New Zealand CO_2 Secondary Supermarkets

2. SYSTEM DESCRIPTION

Figure 2 shows a flow diagram of the type of system used and Figure 3 shows photos. As shown in Figure 2, a cascade system is used for low temperature loads, and liquid overfeed (no expansion device) is used for medium temperature loads. For low temperature, discharge gas from the outlet of the CO_2 compressors is condensed in a heat exchanger with R404A or R134a evaporating on the cold side. Liquid CO_2 from the outlet of this heat exchanger is stored in the CO_2 receiver. Liquid from the receiver is piped to the liquid pump which pressurizes the CO_2, and ensures it remains in a subcooled state. Liquid CO_2 from the pump is piped to low temperature and medium temperature cabinets. The low temperature cabinets have electronic expansion valves, while the medium temperature cabinets have liquid solenoid valves with no expansion of the refrigerant other than pressure drop through the evaporator. Accordingly, the superheat at the outlet of the low temperature cabinets is approximately 5°K, while liquid and vapor approximately 50/50 by mass exits the medium temperature cabinets. Liquid and vapor CO_2 from the display cabinets returns to the CO_2 condenser completing the cycle. Direct expansion is used for the high side of the system.

3. INSTALLATION AND STARTUP

Some important points learned during the installation were:

- To avoid problems with ice formation and clogging, it is very important to keep the system clean and dry.
- A filter/drier was used upstream of all solenoid valves and electronic expansion valves.
- Copper and fittings with sufficient wall thickness for 40 Bar (580 psig) were used.
- No swaged (expanded) copper pipe was used. Roll-stop couplings for were used for interconnecting pipe work.
- Soft drawn copper tubing was used for 1/4 and 3/8 inch tubing.
- Hard drawn copper tubing was required for tubing 1/2 inch and larger.
- The maximum tubing size used was 7/8 inch.
- Instrument grade CO_2 was used due to lower moisture content.
- Controllers were completely programmed and verified prior to start-up.
- Leak detectors/warning lights/sounders and plant room ventilation were checked and operational prior to charging.
- The high side system was thoroughly checked and operating reliably before commencing cooling of cabinets.

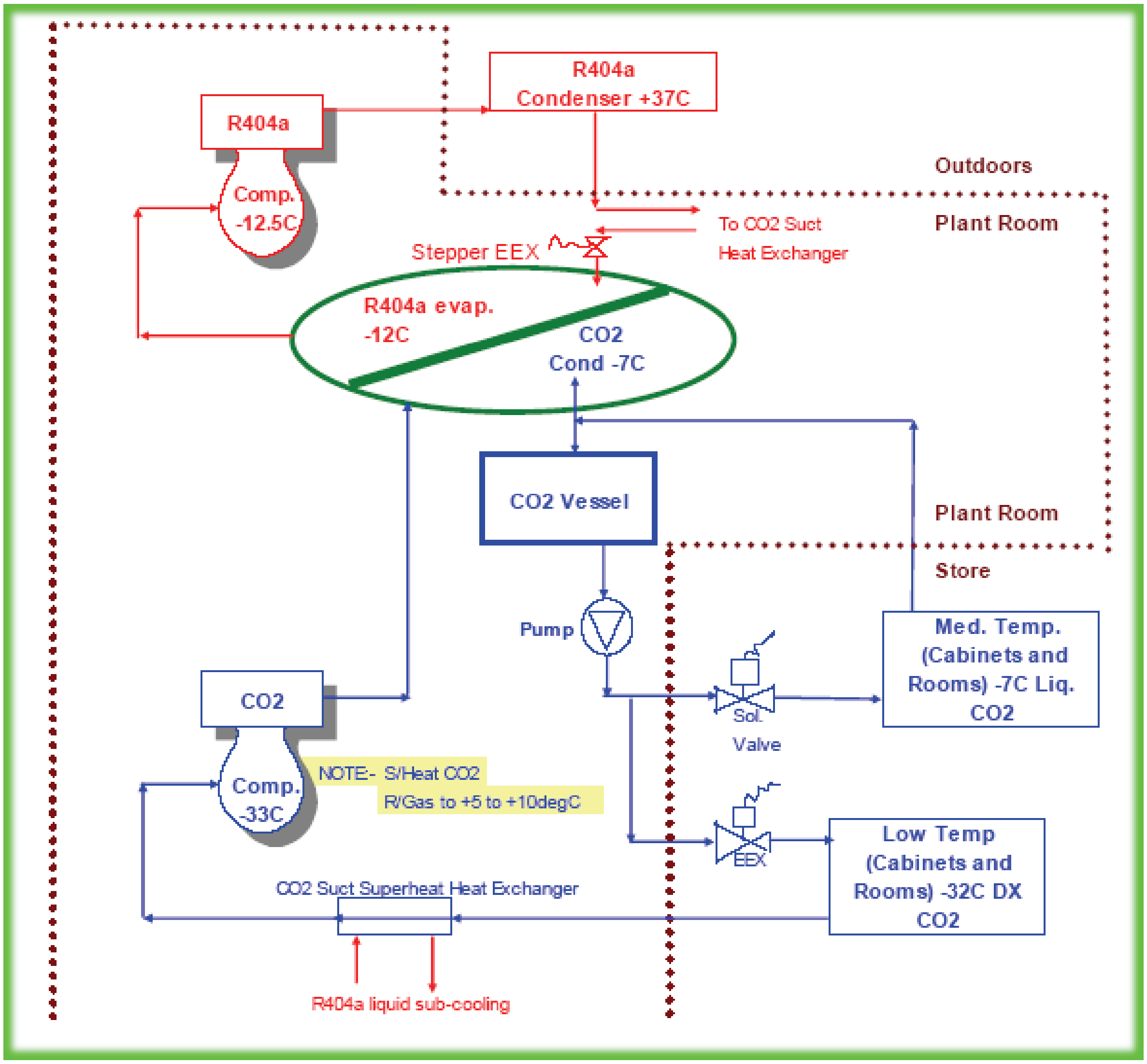

Figure 2: Flow Diagram, Low Temperature Cascade and Medium Temperature Liquid Overfeed System

- CO_2 exhibits very fast heat transfer, and system pressure can rise very rapidly when subjected to high cooling load, such as startup and re-starts. Accordingly, the high-side system cannot respond quickly enough, which may result in high CO_2 pressures and venting. To avoid this situation, loads are timed to stage on at set intervals in the event of a system re-start.
- Pressure limiting devices such as check valves were used anywhere in the system liquid CO_2 could be trapped. Pressure relief valves were used as primary relief to atmosphere. Relief to atmosphere was done from the top of the receiver to vent vapor only.
- Operating pressures are relatively high compared to HFC's. Cascade suction pressure is approximately 175 psig, and discharge pressure is approximately 400 psig.
- Individual display case temperature controllers were used and are recommended.

Figure 3: Photographs of Systems

4. OPERATION

Figure 4 shows discharge air temperature for a medium temperature, multi-deck dairy case over 24 hours. As shown, the discharge air was typically 0°C, +/- 1°C, except during defrost. Similarly, Figure 5 shows discharge air temperature for a wide-island freezer cabinet over 24 hours. Again, the discharge air control was good, typically -27°C, +/- 1°C.

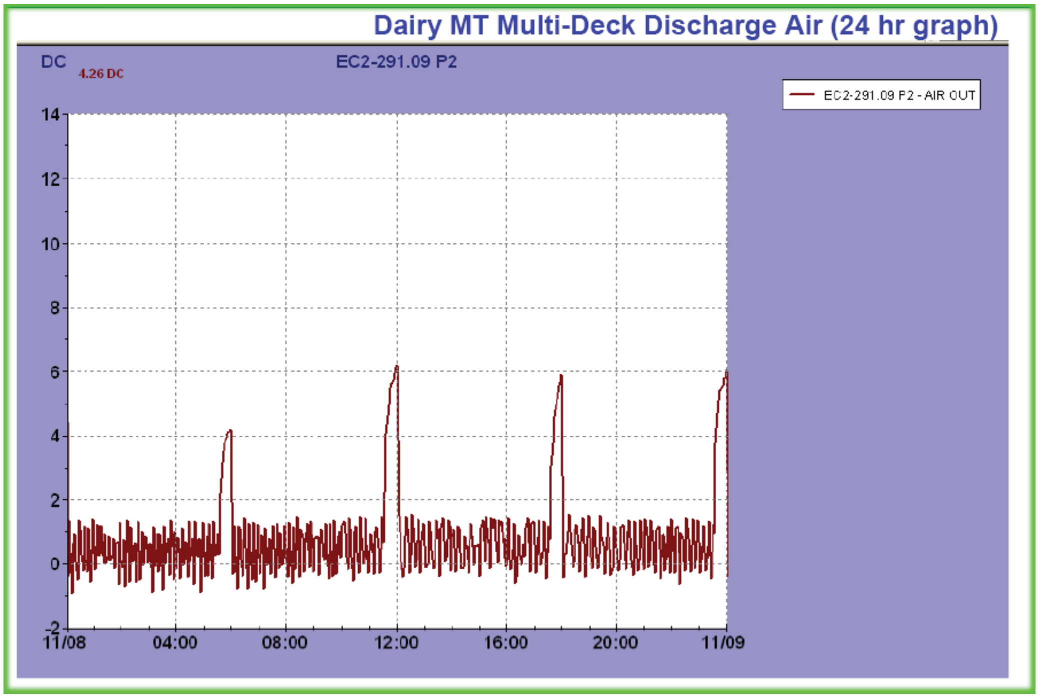

Figure 4: Discharge Air Temperature Multi-Deck Dairy Cabinet, 24 Hours

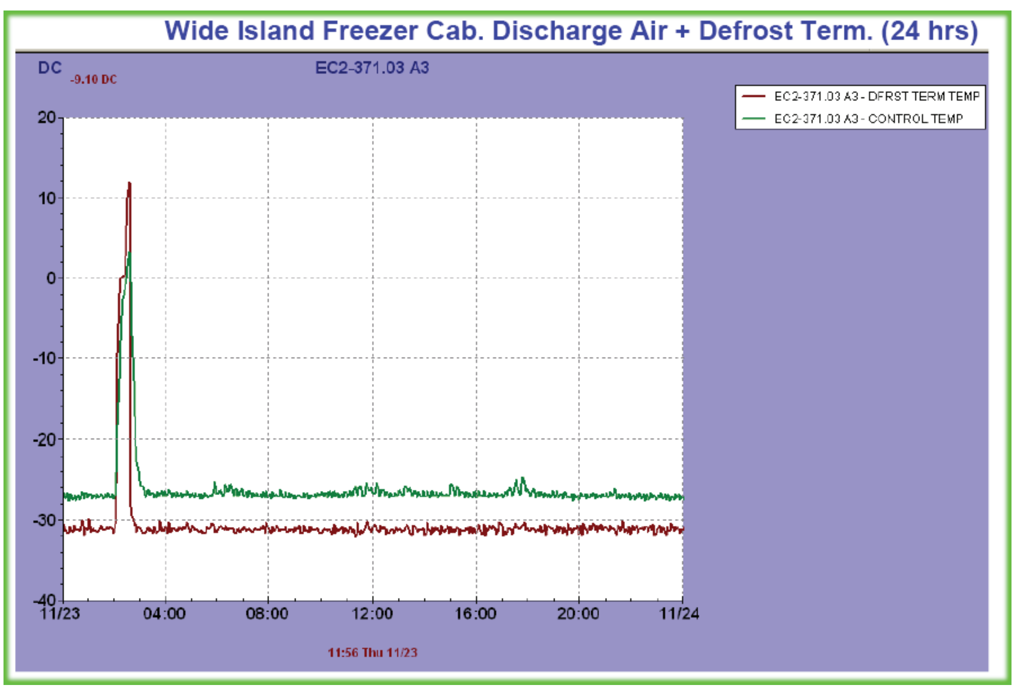

Figure 5: Discharge Air Temperature, Wide-Island Freezer Cabinets, 24 Hours

Figure 6 and 7 show CO_2 vessel pressure and Percent System Loading, respectively. As show in Figure 6, the CO_2 vessel pressure was typically approximately 400 psig +/- 10 psig. As shown in Figure 7, all compressors on the primary system ran for short times between 12:00 and 16:00. The primary system did not appear to be undersized.

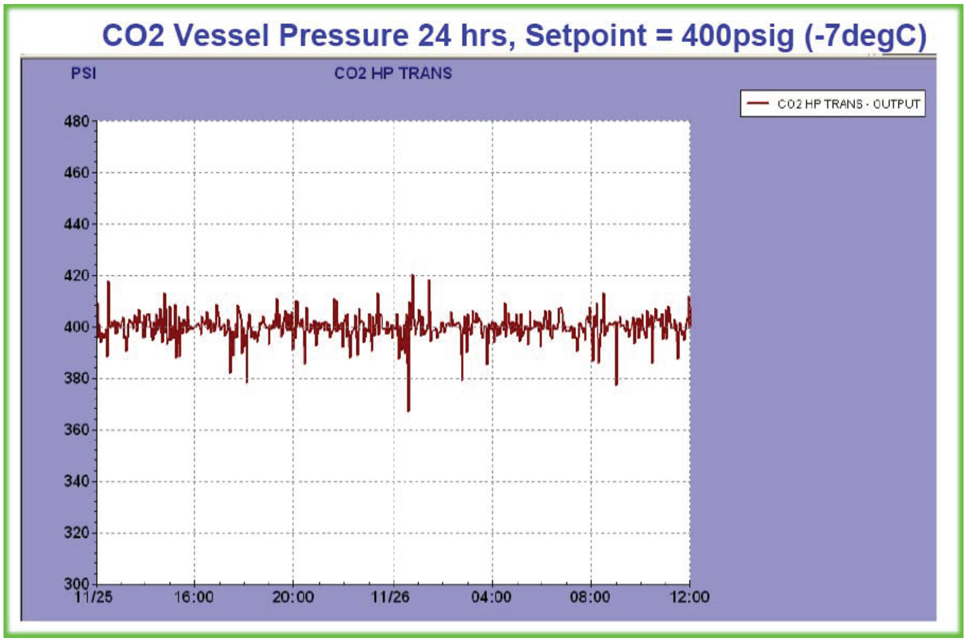

Figure 6. CO_2 Vessel Pressure, 24 Hours

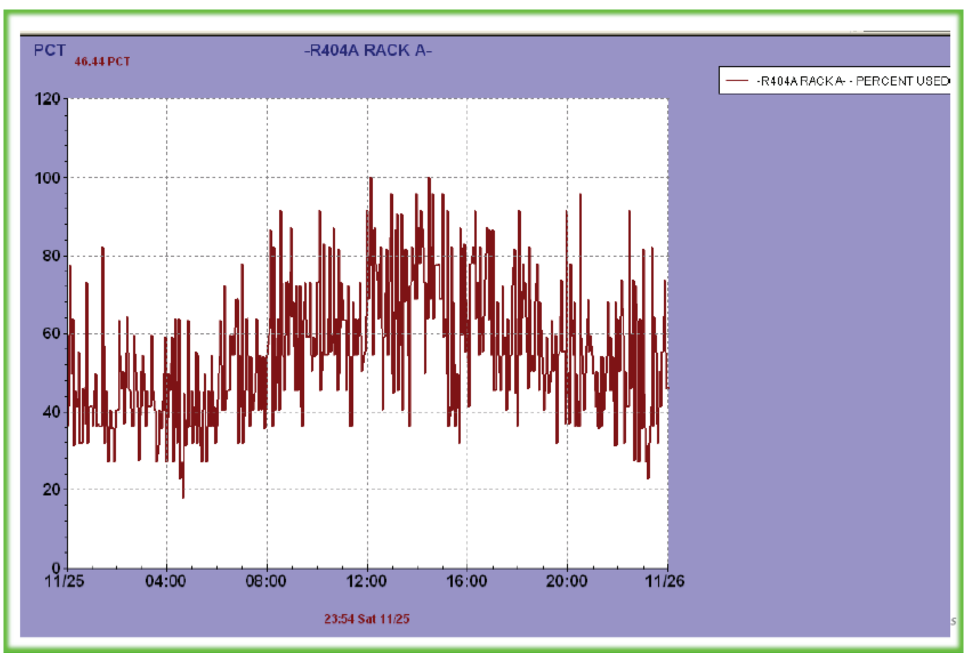

Figure 7: Percent Loading of R404A Primary System

Figure 8 compares energy use between the Christchurch #1 CO_2 site and a nearly identical nearby R404A direct exapnsion site. The x-axis shows dates, and the y-axis shows percent energy savings. Thus, positive values indicate *lower* energy use for the CO_2 site, and negative values indicate lower energy use for the R404A site. As shown, the CO_2 site typically had roughly 4% to 6% lower energy use. Further, on 25 December 2006, the R404A site showed roughly 9% lower energy use. This was caused by the cabinets' night blinds being left open at the CO_2 site on Christmas Day.

Annual energy savings in the first twelve months figures to approximately 101,000 KWH. The lower energy use may be due to the fact that the CO_2 system is a cascade type system which, other things being equal, typically have lower energy use at high temperature lift conditions (December, January, February, and March are warm months in New Zealand).

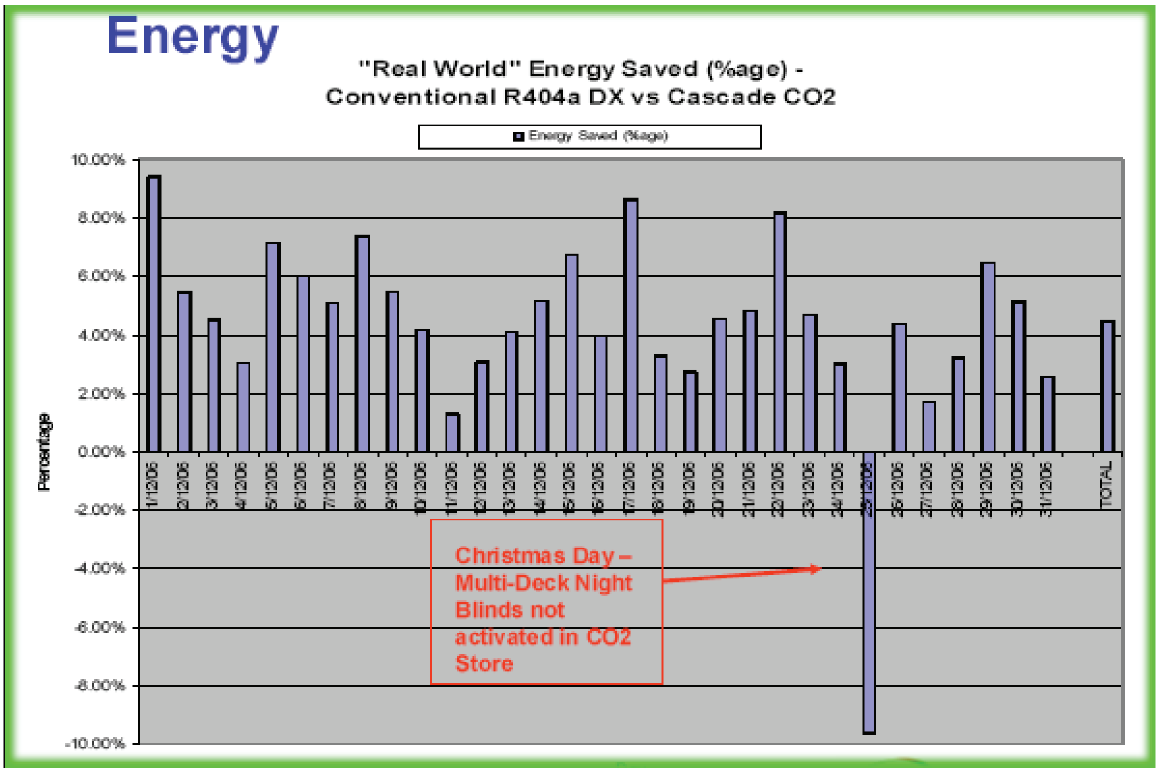

Figure 8. Percent energy savings for Christchurch #1 CO_2 site versus nearby similar R404A direct expansion site

5. GLOBAL WARMING

Finally, Figure 9 shows calculated warming effects for the Christchurch #1 CO_2 site and the nearby R404A direct expansion site. The Christchurch #1 site uses 538 kg of CO_2 plus 166 kg of R404A, 74% less R404A than the direct expansion site which uses 626 kg of R404A. Further, the Christchurch #1 site uses 1140 MWH annually, 5% less than the R404A site which uses 1200 MWH annually. As shown, the total warming effect is approximately 828,000 kg CO_2 for the Christchurch #1 site, 29% lower than the R404A direct expansion site.

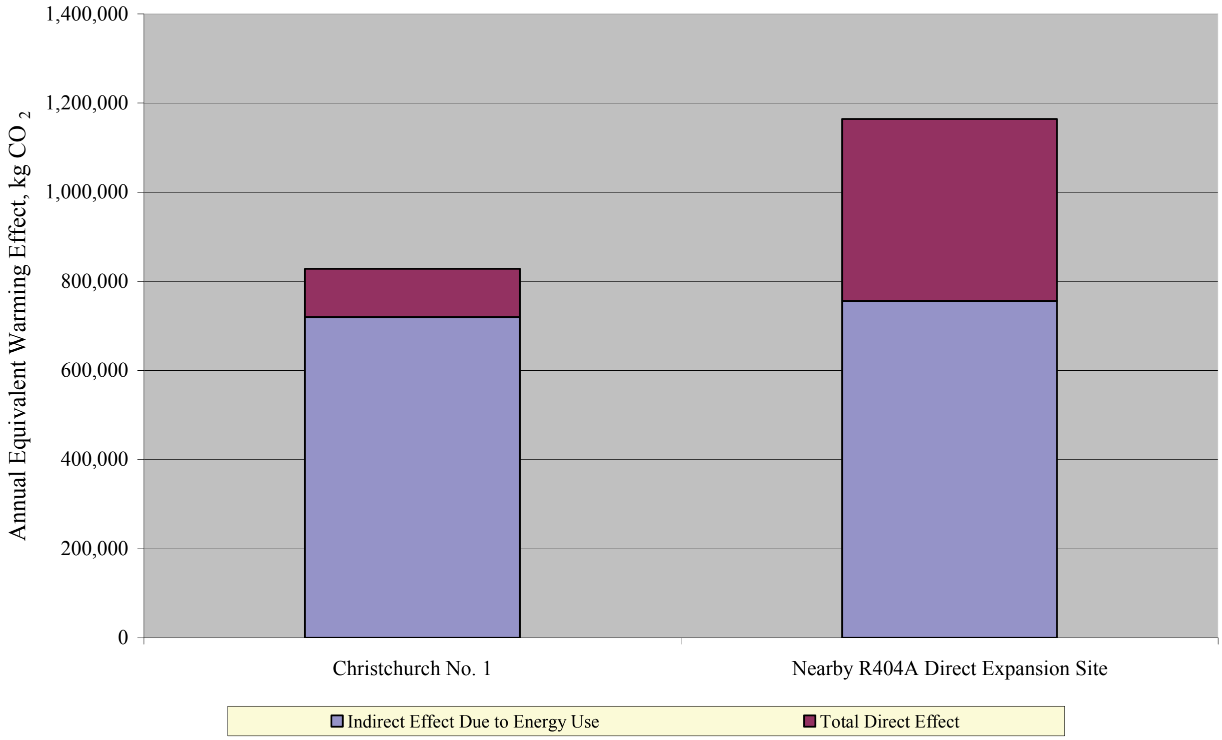

Figure 9. Annual equivalent effect of Christchurch #1 CO2/R404A site and nearby R404A direct expansion site

6. SITES IN OPERATION AND PLANNED

As of March 2008, the following sites were running or planned:

1. Location: Christchurch #1, New Zealand
   Opened November 2006 R404A High Side with reciprocating compressors
   Low Temperature Cooling, 62.4 KW
   Medium Temp Cooling, 356.2 KW

2. Nelson (city at the top of New Zealand's South Island)
   Opened March 2007
   R404A High Side with Reciprocating Compressors

3. Christchurch #3, New Zealand
   Opened July 2007
   R404A High Side with Reciprocating Compressors

4. Sydney, Australia
   Opened September 2007
   R134a High Side with Screw Compressors
   Low Temperature Cooling, 61.8 KW
   Medium Temperature Cooling, 338.5 KW

5. Dunedin, New Zealand
   This location is a refurbishment, and will retain the existing R22 parallel compressor system for the high side, albeit with some modifications. Re-use of the existing R22 system minimizes capital cost.

6. Bay of Plenty, New Zealand
   Currently being tendered by four (4) refrigeration contractors.

7. and 8. In discussions with customers in New Zealand and Australia

6. CONCLUSIONS

CO_2 secondary systems are being applied successfully in supermarket refrigeration in New Zealand and Australia. Three sites have been installed in New Zealand and one in Australia through March 2008, and additional sites are planned. For the first site, overall carbon footprint was reduced 29%, R404A charge was reduced 74%, and energy use was reduced approximately 5% on average compared to a similar R404A direct expansion system. Timers were used to ensure loads would be staged on after, for example, an unplanned shutdown. To ensure adequate temperature control, individual display cabinet control is recommended.

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